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Diversity, relative abundance, new locality records, and updated fish fauna of the Ross Sea region

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Abstract: Two surveys were carried out in the Ross Sea region during February and March 2004 and 2008 from the New Zealand RV *Tangaroa*. Fishes were sampled on the continental shelf and slope of the Ross Sea, and on adjacent seamounts to the north, mainly using a large demersal fish trawl and a large mesopelagic fish trawl. Parts of the shelf and slope were stratified by depth and at least three random demersal trawls were completed in each stratum, enabling biomass estimates of demersal fish to be calculated. Fish distribution data from these two surveys were supplemented by collections made by observers from the toothfish fishery. A diverse collection of over 2500 fish specimens was obtained from the two surveys representing 110 species in 21 families. When combined with previous documented material this gave a total species list of 175, of which 135 were from the Ross Sea shelf and slope (to the 2000 m isobath). Demersal species-richness, diversity and evenness indices all decreased going from the shelf to the slope and the seamounts. In contrast, indices for pelagic species were similar for the slope and seamounts/abyss but were much lower for the shelf.

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Key words: Antarctica, demersal fish, mesopelagic fish, species-richness

Introduction

Compared to the Weddell Sea there has been limited scientific sampling of fishes in the Ross Sea, with few systematic surveys aimed at describing the community of fishes. Recent major studies of the Ross Sea fish fauna include Eastman & Hubold (1999) who recorded 47 demersal species including four new species. Donnelly *et al.* (2004) reported 45 species of benthic and pelagic fishes sampled from midwater and bottom trawls in areas in the eastern Ross Sea, and found highest diversity between 450 and 500 m depth. La Mesa *et al.* (2006) and Vacchi *et al.* (2000) sampled relatively shallow depths down to 700 m using gill and trammel nets, longlines, traps, and Agassiz trawls in the western Ross Sea. These and other studies have highlighted the need to employ a variety of sampling methods to obtain representative samples of the fishes which range from small benthic species such as barbeled plunderfishes (Artedidraconidae) to large semi-pelagic species such as the Antarctic toothfish (*Dissostichus mawsoni*).

The New Zealand Government has funded two expeditions to survey Ross Sea biodiversity using the RV *Tangaroa*. The first survey (termed BioRoss) sampled demersal species in the area off Cape Adare in the north-west of the Ross Sea and also at the Balleny Islands in 2004 (Mitchell & Clark 2004). The second (termed IPY-CAML) sampled demersal and midwater species on the continental shelf and slope of the Ross Sea as well as the Admiralty and Scott seamounts to the north of the Ross Sea down to depths of 3500 m (Hanchet *et al.* 2008a). Clark *et al.* (2010) examined the distribution of 65 demersal fish species taken during these two surveys to determine if demersal fish communities varied throughout the region, and considered environmental factors that might influence the communities. Three broad assemblages were identified, in the southern Ross Sea, central-northern Ross Sea, and the seamounts further north where some species more typical of sub-Antarctic latitudes were observed.

The pelagic fish fauna of the Ross Sea was first analysed by de Witt (1970), who concluded that catches over the continental shelf was almost entirely (99%) dominated by the Antarctic silverfish (*Pleuragramma antarctica*) and that oceanic pelagic fishes, such as lanternfishes (Myctophidae) were confined to the north. Donnelly *et al.* (2004) classified the pelagic assemblages as either oceanic or continental shelf. The pelagic assemblage (0–1000 m) was dominated by four families (bathylagids, gonostomatids, myctophids, paralepids) but these were replaced over the continental shelf by notothenioids, primarily *P. antarctica*. O'Driscoll *et al.* (2011) presented preliminary results of midwater trawling from the IPY-CAML survey focusing on the distribution and biomass of *P. antarctica* in the western Ross Sea.

An exploratory longline fishery by New Zealand flagged vessels for toothfish (*Dissostichus* spp.) has operated in the

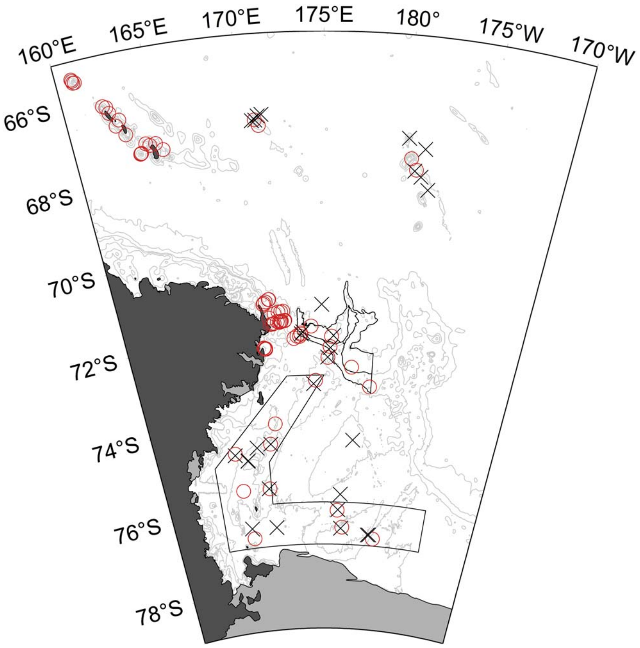

Fig. 1. Survey area showing demersal (o) and midwater (x) trawl locations. Depth contours at 200, 400, 600, 1200, and 2000 m and boundaries of shelf and slope strata.

Ross Sea region, north to 60°S (CCAMLR Subarea 88.1) since 1998 (Hanchet *et al.* 2010). The fishery operates at depths of 600–1800 m on the shelf and slope of the Ross Sea as well as the banks, ridges, and seamounts to the north. Although estimates of *D. mawsoni* abundance and sustainable yields are available (SC-CAMLR 2011), the abundance of the main demersal bycatch species such as macrourids has proved more difficult to assess (Hanchet *et al.* 2008b). Therefore, one of the main objectives of the IPY-CAML survey was to estimate the relative abundance of demersal fish on parts of the continental shelf and slope of the Ross Sea. Over the course of the fishery many specimens have been collected by observers and registered into the New Zealand National Fish Collection at the Museum of New Zealand Te Papa Tongarewa (Te Papa). This has led to the description of several new species of fishes (e.g. Møller & Stewart 2006, Eakin *et al.* 2009), and these, plus other Te Papa specimens which represent new records, are also considered here.

This paper is a contribution to research on the biodiversity of the Ross Sea region of Antarctica as part of the Census of Antarctic Marine Life (CAML) - International Polar Year (IPY). We present the results from two surveys carried out in 2004 and 2008 to obtain new data on the biodiversity of the demersal and pelagic fish fauna of the western Ross Sea (between 160°E and 170°W, south of 71°S) and adjacent northern seamounts (65–68°S). The main aims of the study were to improve our knowledge of fish species diversity, distribution and relative abundance in these two regions. The list of species known from the shelf and slope of the Ross Sea (down to 2000 m) is updated, and a species list for the rest of the Ross Sea region (north to 60°S) is assembled for the first time.

Methods

Survey area

The BioRoss survey took place in January–March 2004, and sampling was carried out along a series of five transects encompassing depths of 123–1165 m between Cape Adare and Cape Hallet in the north-west Ross Sea and on four separate locations at the Balleny Islands (Mitchell & Clark 2004). The IPY-CAML survey was carried out in January–March 2008, and was designed to sample a wide range of habitats and depths covering the continental shelf, slope, abyss, and seamounts at depths of 280–3500 m in the Ross Sea region (Hanchet *et al.* 2008a). The sampling locations of the demersal and midwater trawl stations are shown in Fig. 1.

Vessel and gear specifications

The RV *Tangaroa* is a 70 m long, 2000 GRT, stern trawler owned and operated by the National Institute of Water

Table I. Number of demersal trawls carried out for the BioRoss (BioRoss) and IPY-CAML (IPY) surveys, and number of mark identification and core midwater trawls carried out for the IPY-CAML survey.

Area	Seabed depth range (m)	Number of stations			
		Demersal trawl (BioRoss)	Demersal trawl (IPY)	Midwater mark identification	Midwater core
Shelf	0–200	2	0	0	0
Shelf	200–400	13	4	3	2
Shelf	400–600	11	3	5	3
Shelf	600–1200	0	4	2	1
Slope	600–1200	8	4	0	2
Slope	1200–2200	0	4	0	3
Seamounts	400–3000	18	4	0	5
Abyss	3000–3600	0	0	1	3
Total		52	23	11	19

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Table II. Fishes of the Ross Sea (RS) adapted from Eastman & Hubold (1999) including the mesopelagic and demersal fauna of the shelf and slope down to a depth of 2000 m (northern limit is Cape Adare and Iselin Bank at about 71–72°S) and the rest of the Ross Sea region (RSR) 71–72° north to 60°S with an eastern limit at 150°W and western limit at 160°E (Ross dependency). Includes original source (a = Eastman & Hubold 1999, b = Gon & Heemstra 1990, c = new record after 1999) as well as all specimens recorded in this study (d = BioRoss and/or IPY-CAML surveys, e = NZ longline toothfish fishery). Species names are from Gon & Heemstra (1990), Eastman & Eakin (1999) and Eschmeyer & Fricke (2011). Family names are from Nelson (2006).

Fish species	RS	RSR
Etmopteridae (lantern sharks)		
Etmopterus sp. BA	e	
Somniosidae (sleeper sharks)		
Somniosus antarcticus Whitley	e	
Rajidae (hardnose skates)		
Amblyraja georgiana (Norman)	a,e	d
Arhynchobatidae (softnose skates)		
Bathyraja maccaini Springer	a,d	
Bathyraja n. sp. cf. *eatonii* (Günther)	a,d,e	
Bathyraja n. sp. (dwarf) (Stehmann & Bürkel in Gon & Heemstra)	a,d,e	
Synaphobranchidae (cutthroat eels)		
Diastobranchus capensis Barnard		e
Histiobranchus bathybius (Günther)	e	
Nemichthyidae (snipe eels)§		
Avocettina sp.	e	
Serrivomeridae (sawtooth eels)§		
Serrivomer sp.		d
Bathylagidae (deepsea smelts)§		
Bathylagus antarcticus Günther	a	d
Alepocephalidae (slickheads)§		
Genus & species undifferentiated		d
Gonostomatidae (bristlemouths)§		
Cyclothone kobayashii? Miya	c[1]	c[1]
Cyclothone microdon (Günther)	d	b,d
Gonostoma bathyphilum (Vaillant)	d	
Stomiidae (barbeled dragonfishes)§		
Borostomias antarcticus (Lönnberg)		d
Scopelarchidae (pearleyes)§		
Benthalbella elongata (Norman)	d	
Paralepididae (barracudinas)§		
Anotopterus pharao Zugmayer	d	d,e
Magnisudis prionosa (Rofen)		e
Notolepis coatsi Dollo	a,d	b,d
Myctophidae (lanternfishes)§		
Electrona antarctica (Günther)	a,d	b,d
Electrona carlsbergi (Tåning)		b,d
Gymnoscopelus bolini Andriashev		d
Gymnoscopelus braueri (Lönnberg)	a,d	b,d
Gymnoscopelus fraseri (Fraser-Brunner)		b,d
Gymnoscopelus hintonoides Hulley	d	d
Gymnoscopelus nicholsi (Gilbert)	a,d	b,d
Gymnoscopelus opisthopterus Fraser-Brunner	b,d	
Gymnoscopelus piabilis? (Whitley)		b,d
Krefftichthys anderssoni (Lönnberg)	a	b,d
Nannobrachium achirus (Andriashev)	a,d	b,d
Protomyctophum andriashevi Becker	b	b
Protomyctophum bolini (Fraser-Brunner)	a	b
Protomyctophum kolaevi Prokofiev		c[2]
Protomyctophum tenisoni (Norman)		b
Lampridae (moonfishes)§		
Lampris immaculatus Gilchrist	e	
Muraenolepididae (eel cods)		
Muraenolepis evseenkoi Balushkin & Prirodina	c[3],d	d
Muraenolepis sp. (unidentified)		e
Macrouridae (grenadiers, rattails)		
Coryphaenoides armatus (Hector)		e
Coryphaenoides ferrieri (Regan)		b,d
Coryphaenoides lecointei (Dollo)		b,d

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Table II. Continued

Fish species	RS	RSR
Cynomacrurus piriei Dollo	b,d	b,d
Macrourus caml McMillan, Iwamoto, Stewart & Smith	d[4],e	d[4],e
Macrourus carinatus (Günther)		e
Macrourus holotrachys Günther		e
Macrourus whitsoni (Regan)	a,d,e	b,d,e
Moridae (deepsea cods)		
Antimora rostrata (Günther)	e	d,e
Halargyreus johnsonii Günther		d
Lepidion sp. cf. *schmidti* Svetovidov		e
Lepidion sp. ? *ensiferus* (Günther)		e
Melanocoetidae (black seadevils)§		
Melanocetus rossi Balushkin & Fedorov	e	e
Oneirodidae (dreamers)§		
Oneirodes notius Pietsch	b,e	
Ceratiidae (seadevils)§		
Ceratias tentaculatus (Norman)		e
Gigantactinidae (whipnose anglers)§		
Gigantactis sp.		e
Melamphaidae (bigscale fishes)		
Poromitra antarctica (Norman)		b[5]
Cetomimidae (flabby whalefishes)§		
Gyrinomimus grahami Richardson & Garrick		b
Psychrolutidae (blobfishes)		
Ebinania sp.		e
Liparidae (snailfishes)[6]		
Careproctus ampliceps Andriashev & Stein		
Careproctus catherinae Andriashev & Stein		c
Careproctus inflexidens Andriashev & Stein	c	
Careproctus polarsterni Duhamel	a,c	
Careproctus pseudoprofundicola Andriashev & Stein	c	
Careproctus vladibeckeri Andriashev & Stein	c	c
Genioliparis kafanovi Balushkin & Voskoboinikova	c	
Paraliparis alius Stein		e
Paraliparis amerismos Stein	e	
Paraliparis andriashevi Stein & Tompkins	a,d,e	
Paraliparis antarcticus Regan	a,d,e	d
Paraliparis camilaris Stein	d	
Paraliparis devriesi Andriashev	a,e	
Paraliparis ekaporus Stein	d	
Paraliparis epacrognathus Stein	d	
Paraliparis fuscolingua Stein & Tompkins	a	b
Paraliparis haploporus Stein	d	
Paraliparis longicaecus Stein	d	
Paraliparis macrocephalus Chernova & Eastman	c[7]	
Paraliparis macropterus Stein	d, e	e
Paraliparis magnoculus Stein	e	
Paraliparis mentikoilon Stein	d	
Paraliparis neelovi Andriashev	e	e
Paraliparis nigrolineatus Stein	d	
Paraliparis nullansa Stein	d	
Paraliparis orbitalis Stein	e	
Paraliparis parviradialis Stein	d	
Paraliparis plicatus Stein	d	
Paraliparis posteroporus Stein	d	
Paraliparis rossi Chernova & Eastman	c[7]	
Paraliparis stehmanni Andriashev	d	
Paraliparis tangaroa Stein		e
Paraliparis terraenovae (Regan)	a,d	
Paraliparis voroninorum Stein	d	
Paraliparis n. sp. undetermined	e	
Zoarcidae (eelpouts)		
Dieidolycus leptodermatus Anderson		b

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Table II. Continued

Fish species	RS	RSR
Lycenchelys antarctica Regan	d	
Lycenchelys xanthoptera Anderson	c[8]	
Lycodapus antarcticus Tomo		d
Lycodichthys dearborni (DeWitt)	a,d	
Melanostigma vitiazi Parin		d
Ophthalmolycus amberensis (Tomo, Marschoff & Torno)	a,d	
Ophthalmolycus bothriocephalus (Pappenheim)	a	
Pachycara brachycephalum (Pappenheim)	a,d	
Pachycara sp. 1	d	
Pachycara sp. 2	d	
Seleniolycus laevifasciatus (Tomo, Marschoff & Torno)		d
Seleniolycus pectoralis Møller & Stewart		e
Seleniolycus robertsi Møller & Stewart		e
Zoarcid gen. et sp. 1	d	
Nototheniidae (cod icefishes)		
Aethotaxis mitopteryx DeWitt	a,d	d
Dissostichus eleginoides Smitt	e	b,d,e
Dissostichus mawsoni Norman	a,d,e	b,d,e
Gvozdarus svetovidovi Balushkin	a	
Lepidonotothen larseni (Lönnberg)		b,d
Lepidonotothen squamifrons (Günther)	d	b,d
Notothenia coriiceps Richardson	a,d	b,d
Notothenia rossii Richardson	e	
Paranotothenia dewitti Balushkin	a	
Paranotothenia magellanica (Forster)	b	
Pleuragramma antarctica Boulenger	a,d	b,d
Trematomus amphitreta (Cziko & Cheng)†	c[9]	
Trematomus borchgrevinki Boulenger†	a	e
Trematomus bernacchii Boulenger	a,d	b,d
Trematomus brachysoma Pappenheim†	a,e	b
Trematomus eulepidotus Regan	a,d	d
Trematomus hansoni Boulenger	a,d	b,d
Trematomus lepidorhinus (Pappenheim)	a,d	b,d
Trematomus loennbergii Regan	a,d	b
Trematomus newnesi Boulenger	a,d	b,d
Trematomus nicolai (Boulenger)	a,d	d
Trematomus pennellii Regan	a,d	d
Trematomus scotti (Boulenger)	a,d	b,d
Trematomus tokarevi Andriashev	a,d	b
Artedidraconidae (barbeled plunderfishes)		
Artedidraco glareobarbatus Eastman & Eakin	a	
Artedidraco loennbergi Roule	a,d	b
Artedidraco orianae Regan	a,d	b
Artedidraco shackletoni Waite	a,d	
Artedidraco skottsbergi Lönnberg	a,d	
Dolloidraco longedorsalis Roule	a,d	
Histiodraco velifer (Regan)	a,d	
Pogonophryne albipinna Eakin		a
Pogonophryne barsukovi Andriashev	a,d,e	
Pogonophryne brevibarbata Balushkin, Petrov & Prutka	c[10],e	
Pogonophryne cerebropogon Eakin & Eastman	a	
Pogonophryne immaculata Eakin	d	
Pogonophryne lanceobarbata Eakin	a	
Pogonophryne macropogon Eakin	a	
Pogonophryne marmorata Norman	a,d	
Pogonophryne mentella Andriashev	a,d	
Pogonophryne orangiensis Eakin & Balushkin		e
Pogonophryne permitini Andriashev	a	
Pogonophryne scotti Regan	a,d	
Bathydraconidae (Antarctic dragonfishes)		
Acanthodraco dewitti Skora	e	
Akarotaxis nudiceps (Waite)	a,d	

Table II. Continued

Fish species	RS	RSR
Bathydraco antarcticus Günther	d	
Bathydraco macrolepis Boulenger	a,d	b
Bathydraco marri Norman	a,d	
Bathydraco scotiae Dollo	a,d	
Cygnodraco mawsoni Waite	a,d	
Gerlachea australis Dollo	a,d	
Gymnodraco acuticeps Boulenger	a,d	b,d
Prionodraco evansii Regan	a,d	
Psilodraco breviceps Norman		e
Racovitzia glacialis Dollo	a,d	
Vomeridens infuscipinnis (DeWitt)	a,d	
Channichthyidae (crocodile icefishes)		
Chaenodraco wilsoni Regan	a,d,e	b
Chionobathyscus dewitti Andriashev & Neyelov	c,d,e	d,e
Chionodraco hamatus (Lönnberg)	a,d,e	b
Chionodraco myersi DeWitt & Tyler	a,d,e	b
Cryodraco antarcticus Dollo	a,d,e	b
Cryodraco atkinsoni Regan	c[11],d,e	
Dacodraco hunteri Waite	a,d,e	
Neopagetopsis ionah Nybelin	a,d,e	d
Pagetopsis macropterus (Boulenger)	a,d	b
Pagetopsis maculatus Barsukov & Permitin	a,d,e	b
Chiasmodontidae (swallowers)§		
Kali sp.		d
Gempylidae (snake mackerels)§		
Paradiplospinus gracilis (Brauer)	e	b,d

† = placement in *Trematomus* follows Kuhn & Near (2009), § = families considered to be pelagic.
[1]Donnelly *et al.* (2004), [2]Prokofiev (2005), [3]Balushkin & Prirodina (2010b), [4]McMillan *et al.* (2012), [5]Kotlyar (2009), [6]Stein (2012), [7]Chernova & Eastman (2001), [8]Struthers & Møller (2009), [9]Cziko & Cheng (2006), [10]Balushkin *et al.* (2011), [11]La Mesa *et al.* (2002).

and Atmospheric Research (NIWA). Whilst it has an ice-strengthened hull, it is not an ice-breaker and so was restricted in the areas that she was capable of working. A number of biological sampling gear types were deployed during the surveys (epibenthic sleds, beam trawls and fish trawls).

The NIWA rough bottom trawl net was deployed at 75 stations to sample demersal species between 70 and 1990 m depth (Table I). This net had a mouth width of 25 m and a codend of 60-mm mesh fitted with a 40-mm liner to retain smaller fish. SCANMAR sensors and a netsonde were attached to the doors and net to record doorspread and headline height respectively, and to determine bottom contact time. The doorspread averaged 80 m (range 65–91 m) and the headline height averaged 5.1 m (range 3.8–7.5 m). Standard tows were of 20 min duration at a speed over the ground of three knots.

One of the objectives of the IPY-CAML survey was to determine relative abundance estimates of demersal fish species for selected parts of the Ross Sea shelf and slope using a random stratified trawl survey. The trawl survey of the shelf was focused mainly on icefishes and nototheniids, and the area was stratified by depth into 200–400, 400–600, and 600–1200 m (Fig. 1). The trawl survey of the slope area was designed to target macrourids as they are the main bycatch species in the toothfish fishery (Hanchet *et al.* 2008b). The slope was split by depth and area into four strata based on macrourid catch rates in the fishery, with a geographic split at 178°50'E and a depth split at 1200 m (Fig. 1). Unfortunately the Iselin Bank was covered by thick ice at the time of the survey and so the eastern slope strata could not be surveyed and sampling in the western strata was much reduced. However, at least three random demersal trawls were completed in each of the three shelf strata and the western two slope strata (Table I).

The NIWA mesopelagic midwater trawl was deployed at 30 stations, 19 of these were core stations for sampling biodiversity and an additional 11 were for acoustic mark identification (Table I). This trawl has a circular mouth opening of about 12 m diameter, a cod-end mesh of 10 mm, and is rated to a maximum depth of 1200 m. It is similar to the IYGPT (International Young Gadoid Pelagic Trawl), which was recommended by CAML for sampling pelagic fish layers. At core stations, the midwater trawl was deployed to a maximum depth of 1000 m, or about 50 m above the seabed where water depth was less than 1000 m. The net was then towed obliquely at three knots, hauling warp to achieve an ascent rate of *c.* 20 m per minute. During tows for acoustic mark identification, the midwater trawl was targeted at the mark of interest and towed for 20–30 min at three to four knots.

Other benthic sampling gear deployed included a 4 m wide beam trawl with a 25-mm mesh, a 1 m wide epibenthic sled designed for sampling epifauna on rough terrain, and a fine meshed Brenke sled designed for sampling free-swimming epifauna (Mitchell & Clark 2004, Hanchet *et al.* 2008a). The catches from these sampling gears were not considered here in detail because of differences in the catch composition of each gear type (Clark *et al.* 2010), but new species and locality records from them were included.

Catch sampling and identification

On the BioRoss and IPY surveys, catch samples were sorted at sea, identified to the lowest possible taxonomic level (operational taxonomic unit (OTU)) and weighed on motion-compensating 100 kg scales to the nearest 0.1 kg. Species were identified following Gon & Heemstra (1990) supplemented by subsequently published taxonomic papers on Southern Ocean fishes (e.g. Kuhn & Near 2009, Balushkin & Prirodina 2010b). Vouchers of each OTU were taken, and registered into Te Papa. Tissue samples were also taken from the voucher specimens to include in the Fish barcode of life project. Some specimens were re-examined onshore to confirm accuracy and consistency of identifications and where possible, identifications were crosschecked using DNA barcoding (Smith *et al.* 2012).

After the IPY-CAML survey was completed it was discovered that specimens originally identified as *Macrourus whitsoni* belonged to two species: *Macrourus whitsoni* and a new sympatric species *Macrourus caml* McMillan, Iwamoto, Stewart & Smith (McMillan *et al.* 2012). A small number of *Macrourus* specimens retained for Te Papa were re-identified, but the remaining specimens were discarded during the surveys and so their identity is unknown. For the purposes of the report we have referred to them as *Macrourus* spp. At the time of the preparation of this manuscript specimens of the Family Liparidae captured during the surveys were undergoing taxonomic re-examination and re-evaluation by Dr David Stein, so in the analysis we used only the three OTUs identified at the time of the surveys. The subsequent publication by Stein (2012) has since allowed the new species names to be incorporated into Table II.

Longline fishing for *Dissostichus* spp. has been carried out throughout the Ross Sea region since 1998 (Hanchet *et al.* 2010). Observers have been instructed to collect and retain unusual fish specimens caught on longlines or recovered from toothfish stomachs. These specimens were identified and registered into the Te Papa fish collection. Records from the Te Papa fish collection were examined to determine new location records for fish species in the Ross Sea and the rest of the Ross Sea region defined here as the area extending north from the Ross Sea to 60°S and from 150°E–150°W.

Data analyses

Diversity conventionally consists of two elements: the number of taxa present (species-richness), and the evenness of their relative abundances. It can also be defined in three forms: point (alpha) diversity, regional (gamma) diversity, and the difference in assemblage composition from one point to another or between local and regional diversity (beta diversity) (Koleff *et al.* 2003). We examined alpha diversity (at the station level) and where possible gamma diversity (at the regional level) for the demersal trawls and the midwater trawls separately. Demersal tows where there was gear damage that may have affected the catch were excluded from analysis ($n = 7$).

A preliminary examination of the fish species collected from the demersal trawl showed that they included a number of mesopelagic species such as myctophids, which had presumably been caught during the descent and ascent of the trawl net. To be consistent with previous studies (e.g. Clark *et al.* 2010, Causse *et al.* 2011), these mesopelagic fish species including *P. antarctica*, were excluded from the analyses of species diversity from the demersal trawls. Where the number of species in a trawl was less than three, those trawls were excluded on the assumption that it was unrealistic to expect such a small number of species to be present, and hence those catches were not representative of the real underlying diversity. This reduced the datasets for subsequent analyses to 57 demersal trawls and 18 midwater trawls. Species-richness, and species diversity using the Shannon-Weaver (H) diversity, Margalef's richness (SR), and Pielou's evenness (J) statistics were calculated for each trawl station using PRIMER v6 (Primer-E Ltd). The diversity indices were based on abundance data as most trawls were towed for a similar distance.

The cumulative species-richness was plotted against the cumulative number of tows to assess the adequacy of the survey data for describing species-richness at the regional level. The overall curves were calculated from 1000 permutations based upon different random orders of the tows. The asymptotic richness was estimated from a fitted curve of the form $H = aN/(1+bN)$, where a and b are constants, N is the number of tows sampled, and the asymptote is given by a/b. Where sufficient data were available gamma diversity was estimated for the shelf, slope, and seamount and for the Ross Sea as a whole (shelf and slope) for the demersal and midwater trawl stations separately. Midwater trawl stations made near seamounts and over the abyss were in similar locations and had similar depth characteristics and so were combined for this analysis. For the purpose of these analyses we defined the slope to be between 600 m and 2000 m extending along the northern edge of the Ross Sea.

Catch rates in kg km^{-2} were calculated for the eight most abundant species caught in the demersal trawls by dividing the catch at each station by the area swept (distance between the wings (25 m) multiplied by the distance towed). Relative biomass estimates (and coefficients of variation) and scaled length-frequency distributions for these species in the demersal trawl were estimated for the five shelf and slope strata in the IPY-CAML survey using

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Table III. Specimens of systematic and zoogeographic significance including new species, new locality, and new depth records for species collected during the BioRoss and IPY-CAML surveys, and from the New Zealand toothfish fishery in the Ross Sea and Ross Sea region. Source: OBS = toothfish fishery, with location; BioRoss = BioRoss survey with station number; IPY = IPY-CAML survey with station number (location if taken by beam trawl or epibenthic sled). All records are based on specimens held at the Museum of New Zealand Te Papa Tongarewa. TL = total length, SL = standard length.

Family	Genus and species (number)	Source
New species for the Ross Sea south of 70°S		
Arhynchobatidae	*Bathyraja* sp. cf. *eatonii* (37)	BioRoss: 9, 10, 11, 18, 36, 75, 85, 122, 172, 174. IPY: 70, 109
Macrouridae	*Macrourus caml* (43)	BioRoss: 172, 218, 246, 249. IPY: 106, 121, 144, 265, 279
Liparidae	*Paraliparis* sp. 1–18 (22)	OBS; IPY
Etmopteridae	*Etmopterus* sp. BA (4)	OBS, 71°25'S, 179°13'W; 75°34'–48'S, 168°01'21'W
Zoarcidae	*Pachycara* sp. 1 (3)	IPY: 167
Zoarcidae	*Pachycara* sp. 2 (1)	IPY: 167
Zoarcidae	"*Pachycara*" sp. 3 (1)	IPY: 167
New species for the Ross Sea region north of 70°S		
Serrivomeridae	*Serrivomer* sp. (1)	IPY: 284
Moridae	*Lepidion* sp. cf. *schmidti* (17)	OBS: 60°49'–64°23'S, 165°30'E–171°06'E
New locality records for the Ross Sea south of 70°S		
Synaphobranchidae	*Histiobranchus bathybius* (1)	OBS: 71°04'S, 176°22'E
Nemichthyidae	*Avocettina* sp. (2)	OBS: 75°12'S, 175°10'W
Gonostomatidae	*Cyclothone microdon* (1)	IPY: 133
Gonostomatidae	*Gonostoma bathyphilum* (1)	IPY: 167
Scopelarchidae	*Benthalbella elongata* (1)	IPY: 142
Paralepididae	*Anotopterus pharo* (1)	IPY: 174
Myctophidae	*Gymnoscopelus hintonoides* (3)	IPY: 174
Lampridae	*Lampris immaculatus* (2)	OBS: 71°16'S, 177°26'W
Moridae	*Antimora rostrata* (3)	OBS: 76°57'S, 168°02'E
Melanocoetidae	*Melanocetus rossi* (2)	OBS: 72°23'S, 179°14'W
Oneirodidae	*Oneirodes notius* (1)	OBS: 75°07'S, 176°23'W
Zoarcidae	*Lycenchelys antarctica* (1)	IPY: 167
Nototheniidae	*Dissostichus eleginoides* (1)	OBS: 72°12'S, 174°07'E
Nototheniidae	*Lepidonotothen squamifrons* (3)	IPY: 115
Artedidraconidae	*Pogonophryne immaculate* (1)	OBS: 75°30'S, 171°22'W
Artedidraconidae	*Pogonophryne orangiensis* (1)	OBS: 75°31'S, 172°06'W
Bathydraconidae	*Acanthodraco dewitti* (1)	OBS: 75°01.5'S, 164°50.1'E
Bathydraconidae	*Bathydraco antarcticus* (4)	IPY: 139; 72°05.1'S, 175°33.2'E
Gempylidae	*Paradiplospinus gracilis* (1)	OBS: 71°26'S, 176°24.2'E
New locality records for the Ross Sea north of 70°S		
Rajidae	*Amblyraja georgiana* (x)	BioRoss: 269; 65°28.75S, 161°2.82E
Synaphobranchidae	*Diastobranchus capensis* (1)	OBS: 60°50'S, 165°30'E
Stomiidae	*Borostomias antarcticus* (1)	IPY: 185
Myctophidae	*Gymnoscopelus bolini* (3)	IPY: 293
Myctophidae	*Gymnoscopelus hintonoides* (22)	IPY: 185, 211, 227, 284, 293
Muraenolepididae	*Muraenolepis evseenkoi* (3)	IPY: 182, (69°23.1'S, 178°42.3'W); 258 (67°21.7'S, 179°57.2'W); 269 (67°01.5'S, 170°48.3'W)
Macrouridae	*Coryphaenoides armatus* (1)	OBS: 63°00'S, 171°00'E
Moridae	*Antimora rostrata* (1)	OBS: 63°11.13'S, 171°30.05'E
Moridae	*Halargyreus johnsonii* (7)	BioRoss: 263; IPY 211
Moridae	*Lepidion* sp. cf. *schmidti* (17)	OBS: 60°49'–64°23'S, 165°30' – 171°06'E
Ceratiidae	*Ceratias tentaculatus* (1)	OBS: 66°35'S, 176°8'W
Gigantactinidae	*Gigantactis* sp. (1)	OBS: 65°21'S, 177°5'W
Psychrolutidae	*Ebinania* sp. (5)	OBS: 62°48'–63°11'S, 173°47' – 174°19'E
Zoarcidae	*Lycodapus antarcticus* (10)	BioRoss: 254, 263
Zoarcidae	*Melanostigma vitiazi* (1)	IPY: 211
Zoarcidae	*Seleniolycus laevifasciatus* (3)	BioRoss: 257; IPY: 312
Nototheniidae	*Aethotaxis mitopteryx* (2)	BioRoss: 254
Nototheniidae	*Trematomus borchgrevinki* (3)	66°43'S, 163°15'E
Nototheniidae	*Trematomus eulepidotus* (6)	BioRoss: 261
Nototheniidae	*Trematomus pennellii* (1)	BioRoss: 279
Channichthyidae	*Chionobathyscus dewitti* (5)	OBS: 66°25.9'S, 177°08.7'W
Channichthyidae	*Neopagetopsis ionah* (1)	BioRoss: 263
Chiasmodontidae	*Kali* sp. (1)	IPY: 284

Table III. Continued

Family	Genus and species (number)	Source
Rare Species		
Melanocoetidae	*Melanocetus rossi* (7)	OBS: 70°59'–72°23'S, 179°31'E–179°14'W
Artedidraconidae	*Histiodraco velifer* (11)	IPY: 056, 066, 094, 75°37'S, 169°48'E
Bathydraconidae	*Akarotaxis nudiceps* (4)	IPY: 041, 077; 75°37'S, 169°48'E.
Bathydraconidae	*Bathydraco macrolepis* (5)	IPY: 041, 070, 174
Bathydraconidae	*Cygnodraco mawsoni* (9)	BioRoss: 056, 057, 089; 71°32'S, 170°07'E, 71°20'S, 170°25'E; IPY: 081
Bathydraconidae	*Gerlachea australis* (23)	IPY: 022, 077, 081, 094; 76°36'S, 176°48'E
Bathydraconidae	*Vomeridens infuscipinnis* (4)	IPY: 056
Channichthyidae	*Dacodraco hunteri* (12)	IPY: 022, 041, 056, 070, 077, 101, 74°44'S, 167°03'E, 75°37'S, 169°48'E
New maximum length records		
Family	Genus and species (length)	Source
Melanocoetidae	*Melanocetus rossi* - 146 mm SL	OBS
Zoarcidae	*Lycodapus antarcticus* - 223 mm TL	BioRoss: 254
Zoarcidae	*Lycodichthys dearborni* - 250 mm TL	IPY: 017
Artedidraconidae	*Histiodraco velifer* - 200 mm SL	IPY: 094
Bathydraconidae	*Cygnodraco mawsoni* - 441 mm SL	BioRoss: 089
Channichthyidae	*Dacodraco hunteri* - 300 mm SL	IPY: 070
Channichthyidae	*Neopagetopsis ionah* - 596 mm SL	IPY: 017
New minimum depth records (metres)		
Family	Genus and species (depth)	Source
Bathydraconidae	*Cygnodraco mawsoni* (85)	BioRoss: 128; 71°20'S, 170°26'E
Channichthyidae	*Chaenodraco wilsoni* (50)	IPY: 079
Channichthyidae	*Chionobathyscus dewitti* (358)	IPY: 215 (67°50'S, 179°34'W)
New maximum depth records (metres)		
Family	Genus and species (depth)	Source
Nototheniidae	*Trematomus lepidorhinus* (1658)	IPY: 144
Bathydraconidae	*Cygnodraco mawsoni* (420)	IPY: 089
Bathydraconidae	*Gymnodraco acuticeps* (936)	IPY: 123 (72°19'S, 175°27'E)
Channichthyidae	*Chionodraco myersi* (926)	IPY: 041
Channichthyidae	*Dacodraco hunteri* (926)	IPY: 041
Channichthyidae	*Neopagetopsis ionah* (1587)	IPY: 133
Channichthyidae	*Pagetopsis macropterus* (752)	IPY: 070
Channichthyidae	*Pagetopsis maculatus* (50)	IPY: 024

the NIWA TrawlSurvey analysis program. The following assumptions were made for estimating biomass: the area swept during each tow equalled the distance between the wings (25 m) multiplied by the distance towed, and that values of vulnerability, vertical availability, and areal availability were all equal to 1.0.

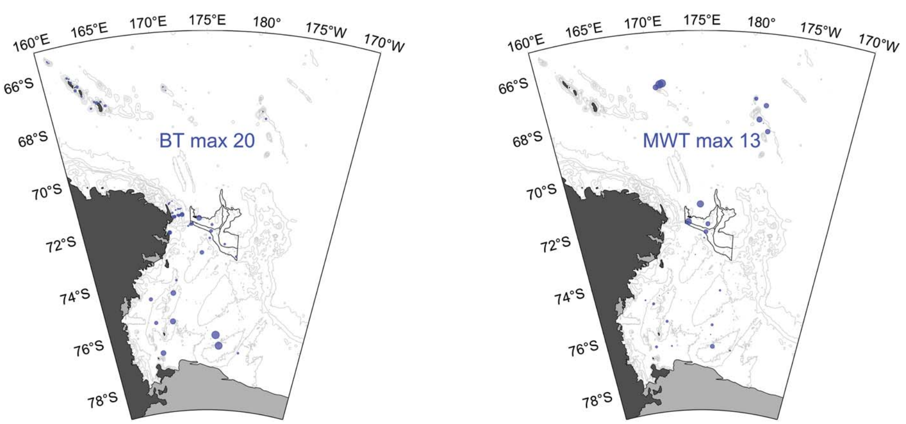

Fig. 2. Spatial distribution of species-richness for demersal fish from demersal tows (left) and for all fish from midwater tows (right). Circle size proportional to species-richness with a maximum of 20 species for demersal trawls and 13 species for midwater trawls. Depth contours at 200, 400, 600, 1200, and 2000 m.

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Table IV. Summary of species-richness, and mean and range of Pielou's evenness, Shannon-Weaver diversity, and Margalef's richness diversity indices at the regional level and the Ross Sea (shelf and slope combined) for demersal and midwater trawls separately.

	Species-richness		Pielou's evenness		Shannon-Weaver		Margalef's richness	
	No. trawls	No. species	Mean	Range	Mean	Range	Mean	Range
Demersal trawls								
Shelf	32	53	0.79	0.34–0.99	1.47	0.54–2.38	1.98	0.83–4.20
Slope	9	26	0.52	0.11–0.96	0.86	0.24–1.55	1.43	0.84–2.06
Seamounts	16	26	0.53	0.02–0.91	0.90	0.02–1.77	1.05	0.29–2.12
Ross Sea	41	62	0.73	0.11–0.99	1.34	0.24–1.55	1.86	0.83–4.20
Midwater trawls								
Shelf	6	11	0.06	0.01–0.11	0.09	0.01–0.06	0.52	0.22–0.96
Slope	5	15	0.79	0.69–0.94	1.51	0.84–1.84	1.38	0.65–1.94
Seamounts/abyss	7	18	0.74	0.66–0.87	1.64	1.20–1.92	1.59	0.95–2.14
Ross Sea	11	24	0.39	0.01–0.94	0.73	0.01–1.84	0.91	0.21–1.94

Results

Species composition

Station details, catch weight, and species-richness for all the demersal and midwater trawls are given in Tables S1 & S2, which will be found at http://dx.doi.org/10.1017/S0954102012001265. A total of 75 demersal trawls were made over the two surveys with a combined total catch weight of 4862 kg (Table S1). Catches were dominated by *Lepidonotothen squamifrons* (59% by weight and 57% by number), *Macrourus* spp. (25% and 11%), and *P. antarctica* (3% and 18%). Catches per tow varied considerably between areas ranging from 0–50 kg on the shelf, 2–430 kg on the slope and 2–1470 kg on the seamounts. Catches on the shelf were dominated by *P. antarctica*, *Trematomus eulepidotus*, *Neopagetopsis ionah* and *Chionodraco hamatus*. Catches on the slope and seamounts were dominated numerically by *Macrourus* spp. and *L. squamifrons* respectively. The demersal trawls recorded 74 species/OTUs in the Ross Sea (of which 11 were considered pelagic) and 38 from the rest of the Ross Sea region (13 pelagic). Based on the OTUs most of the demersal species were from five families: Nototheniidae, Artedidraconidae, Bathydraconidae, Channichthyidae, and Zoarcidae.

A total of 30 midwater trawls were made during the IPY-CAML survey with a combined total catch weight of 1030 t (Table S2, which will be found at http://dx.doi.org/10.1017/S0954102012001265). Catches were dominated by *P. antarctica* (91% by weight and 93% by number), followed by channichthyiids (4.2% and 0.3%), and myctophids (2.7% and 4.1%). The midwater trawls recorded 23 species from the Ross Sea and 21 species from the rest of the Ross Sea region.

A total of 3941 specimens have been registered to date into the Te Papa National Fish Collection from the Southern Ocean, including 1363 specimens from the BioRoss survey and 1271 specimens from the IPY-CAML survey. All species caught during these two surveys are listed in Table II. The revised list of species for the Ross Sea includes the original species list for the Ross Sea from Eastman & Hubold (1999), subsequent taxonomic publications (e.g. Møller & Stewart 2006, Balushkin & Prirodina 2010a), and the new species and location records from the surveys and toothfish fishery in the current study and equalled a total of 135 species (Table II). The list of species for the rest of the Ross Sea region drew mainly from the species listed in Gon & Heemstra (1990) and the new species and location records

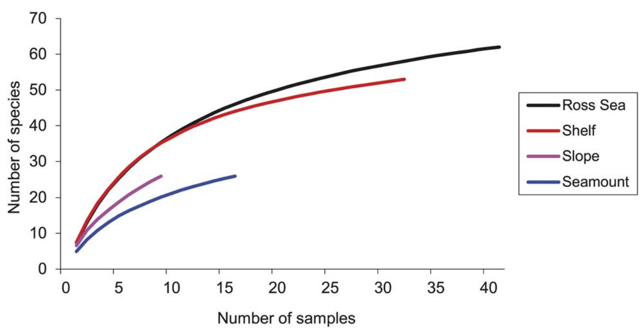

Fig. 3. Number of tows and the cumulative number of demersal fish species sampled by the demersal trawl on the shelf, slope, seamounts, and the Ross Sea (shelf and slope combined). The asymptote for the Ross Sea was 77 species.

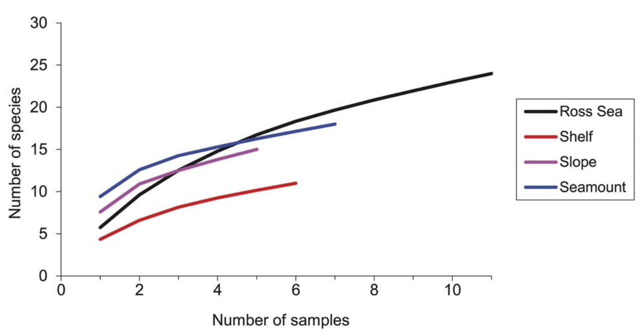

Fig. 4. Number of tows and the cumulative number of fish species sampled by the midwater trawl for the shelf, slope, seamounts, and the Ross Sea (shelf and slope combined). The asymptote for the Ross Sea was 35 species.

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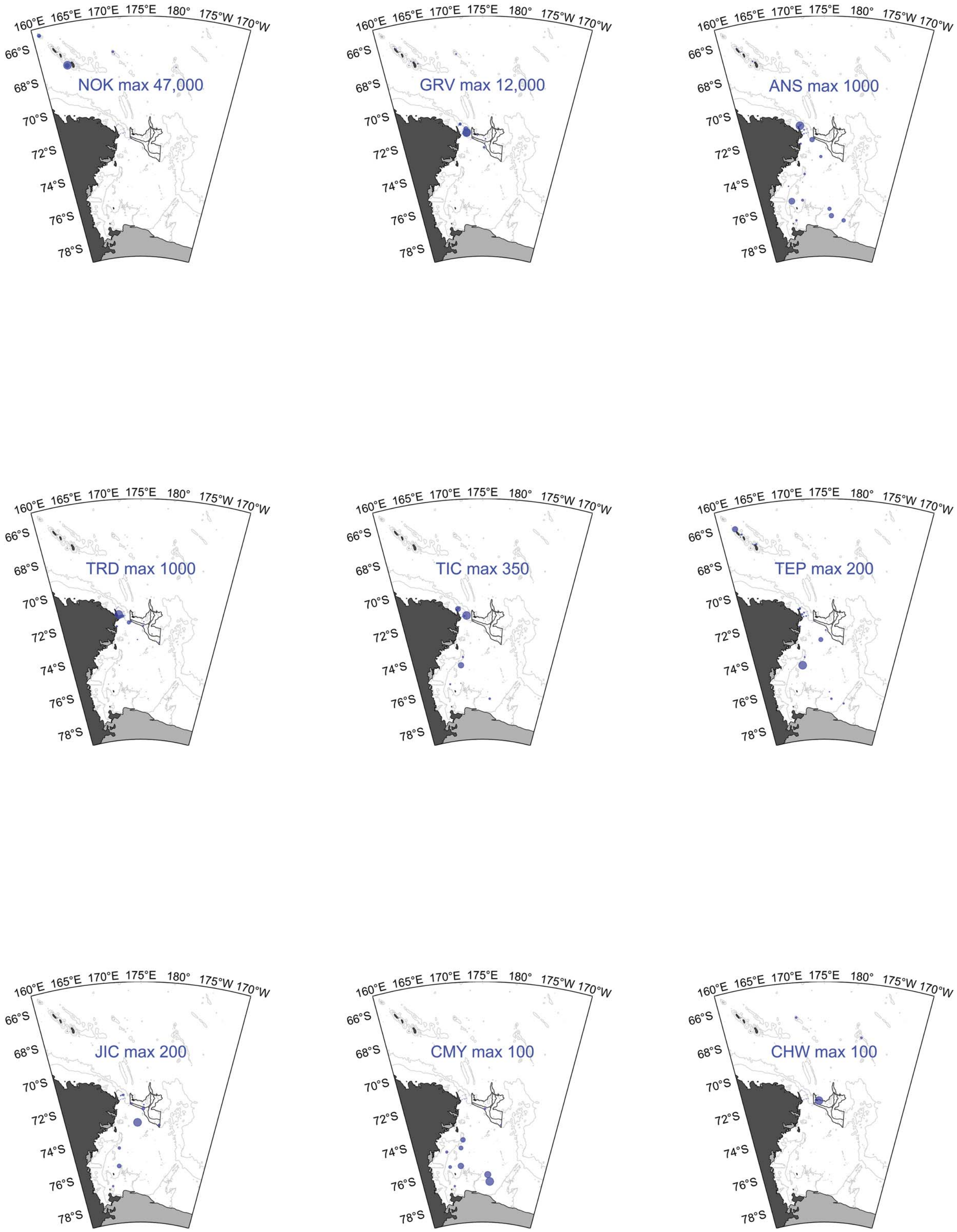

Fig. 5. Spatial distribution of catch rates (kg km^{-2}) for NOK, *Lepidonotothen squamifrons*; GRV, *Macrourus* spp.; ANS, *Pleuragramma antarctica*; TRD, *Trematomus lepidorhinus*; TIC, *Chionodraco hamatus*; TEP, *Trematomus eulepidotus*; JIC, *Neopagetopsis ionah*; CMY, *Chionodraco myersi*; CHW, *Chionobathyscus dewitti*. Circle area proportional to catch rate with maximum catch rate shown for each species.

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from the current study and equalled a total of 95 species (Table II). The total species count for the entire Ross Sea region equalled 175 species. The noteworthy systematic and zoogeographic findings from this study are presented in more detail in Table III.

Diversity indices

Species-richness at the alpha level ranged from 1–13 for the midwater trawls and 1–20 for the demersal trawls (Tables S1 & S2, which will be found at http://dx.doi.org/10.1017/S0954102012001265). The highest richness for demersal fish occurred at two stations on the shelf in 350–450 m, and in general declined northwards from the shelf to the northern seamounts (Fig. 2, Table IV). In contrast, species-richness for pelagic fish was greatest in the northern seamounts/abyssal stations and declined southwards to the shelf.

The species-richness at the gamma level for demersal trawls was highest on the shelf with 53 species whilst the slope and seamounts each had 26 species (Table IV). However, the cumulative species-richness curves for the demersal fish species for the regions were not yet asymptotic, indicating that the richness was not fully sampled and more trawls were made on the shelf than in the other two regions (Fig. 3). A more valid comparison of gamma diversity can be obtained by comparing species-richness between regions for a given number of trawls. Based on a sample of ten trawls gamma diversity was highest on the shelf, intermediate on the slope and lowest on the seamounts (Fig. 3). The Shannon-Weaver and Margalef diversity indices showed very similar patterns, with the mean value for seamounts being *c.* 50–60% of the mean value for the shelf (Table IV). The Pielou's statistic suggested that catches were more even on the shelf than on the slope and seamounts where catches were sometimes dominated by large catches of *L. squamifrons* or *Macrourus* spp. A fitted curve estimated the asymptotic richness at 77 demersal species for the Ross Sea (shelf and slope) as a whole.

The species-richness at the gamma level for midwater trawls was highest on the seamounts/abyss with 18 species, followed by the slope with 15 species and the shelf with 11 species (Table IV). However, the cumulative species-richness curves again indicated that the richness was not fully sampled (Fig. 4). Based on a sample of five trawls gamma diversity was similar for the seamounts/abyss and slope and lowest on the shelf (Fig. 4). The Shannon-Weaver and Margalef diversity indices showed similar patterns, with the seamount/abyss having slightly higher diversity and richness than the slope (Table IV). However, the values for the Shannon-Weaver and Pielous evenness statistics on the shelf were very low reflecting the dominance of *P. antarctica* at these stations. A fitted curve estimated the asymptotic richness at 35 pelagic species for the Ross Sea as a whole.

Catch rates and biomass

The spatial distribution of the nine most abundant species caught by demersal trawl was highly variable (Fig. 5). *Lepidonotothen squamifrons* was most abundant in depths of 100–400 m on the seamounts with the highest catch rates from around the Balleny Islands. They were virtually absent from the Ross Sea, and so mean catch rates and biomass for the shelf and slope strata are not presented. The highest catch rates of *Macrourus* spp. came from the two slope strata at depths of 600–2000 m (Table V, Fig. 5). They were caught in lower numbers from the seamounts and were absent from deeper waters of the shelf south of the shelf break. Mean catch rates of *P. antarctica* were highest at 400–600 m, but they were caught from throughout the shelf region extending in low numbers to the upper slope and the northern seamounts. The highest catch rates of *T. lepidorhinus* were made at 200–600 m from near Cape Adare (Fig. 5), whilst catch rates further

Table V. Stratum details, and mean catch rates (and standard deviations) in kg km^{-2} by stratum for the eight most abundant species and for all fish species combined.

	Stratum				
	1	2	3	4	5
Number of trawls	3	3	4	3	3
Depth range	200–400	400–600	600–1200	600–1200	1200–2000
Stratum area (km^2)	20 663	36 175	44 806	6589	14 317
Chionobathyscus dewitti	0	0	0	0	26 (44)
Chionodraco myersi	40 (49)	41 (24)	12 (15)	3 (3)	0
Chionodraco hamatus	65 (96)	5 (6)	3 (6)	0	0
Macrourus spp.	0	0	0	148 (156)	234 (198)
Neopagetopsis ionah	68 (100)	15 (26)	2 (4)	0	0
Pleuragramma antarctica	148 (171)	285 (259)	85 (90)	3 (6)	0
Trematomus eulepidotus	84 (92)	1 (1)	3 (4)	0	0
Trematomus lepidorhinus	5 (5)	18 (17)	4 (9)	18 (12)	5 (5)
All species combined	964 (566)	547 (263)	164 (96)	280 (189)	422 (281)

Table VI. Relative biomass estimates and coefficients of variation (c.v.%) of the eight most abundant fish species, and for all fish species combined, caught from demersal trawl stations in the shelf and slope strata.

Species	Shelf		Slope	
	Biomass (t)	c.v.%	Biomass (t)	c.v.%
Chionobathyscus dewitti	0	-	365	100
Chionodraco myersi	3573	29	18	63
Chionodraco hamatus	1771	68	0	-
Macrourus spp.	0	-	4332	40
Neopagetopsis ionah	2423	62	120	30
Pleuragramma antarctica	22 472	39	21	100
Trematomus eulepidotus	1918	58	0	-
Trematomus lepidorhinus	1293	45	197	30
All species combined	55 745	19	6390	31

south in the shelf stratum and on the slope were much lower and they were absent from the seamounts. In contrast, catch rates of *T. eulepidotus* were highest at 200–400 m on the Ross Sea shelf (Table V) and seamounts (Fig. 5) and lower in deeper water elsewhere. Catch rates of *C. hamatus* and *N. ionah* were highest in the 200–400 m strata on the Ross Sea shelf (Table V), with generally lower catch rates in deeper waters of the shelf and the slope (Fig. 5). However, the highest catch of the former was from the upper slope off Cape Adare at 630 m. Although *N. ionah* was recorded from a demersal trawl at 1600 m depth it is possible that they were caught in midwater whilst the net was ascending or descending. Catch rates of *C. myersi* were highest in the 200–600 m depth strata (Table V) and they had a more southern distribution (Fig. 5). All three species were absent from catches on the seamounts. In contrast, *C. dewitti* was confined to the deeper waters of the slope and seamounts (Table V, Fig. 5).

The total biomass in the shelf strata was 55 745 t (coefficient of variation 19%), whilst the total biomass on the slope strata was 6390 t (coefficient of variation 31%). The species with the highest biomass in the shelf strata was *P. antarctica*, which contributed to over 40% of the total biomass (Table VI). The icefish *C. myersi* and *N. ionah* were the two next most abundant species. In contrast, *Macrourus* spp. had the highest biomass in the slope strata, contributing to over 65% of the total biomass (Table VI). Most of the individual species' coefficients of variation were greater than 30% indicating the estimates were very uncertain.

Discussion

New species and locality records

As noted by Eastman & Hubold (1999) our knowledge of the fish fauna of the Ross Sea and adjacent waters is still incomplete. In the current study we have extended that knowledge further by sampling depths and areas that have never previously been sampled. Demersal trawls were deployed to almost 2000 m on the Ross Sea slope and beam trawls to almost 3500 m on the abyssal plain. The Balleny Islands and Scott and Admiralty seamounts were sampled for the first time, and many new location records were obtained from the wide-ranging toothfish fishery.

During the sampling and subsequent analysis six undescribed species were found in four families: Etmopteridae, Rajidae, Macrouridae, and Zoarcidae, as well as 18 newly described species in the family Liparidae (Table III). Two undescribed species in the Families Serrivomeridae and Moridae were found from the rest of the Ross Sea region. In addition we recorded 19 new locality records for the Ross Sea and 23 new locality records for species in the rest of the region, as well as a number of new depth records, maximum lengths etc. Many of the new species and records (particularly of the zoarcids and liparids) came from the two deepest demersal trawls on the slope. Although this study has added to the knowledge of the fish fauna in these regions, there are still uncertainties surrounding the identity of some of the species in this study which could add further to the list. The groups that are not known or completely diagnosed include the Muraenolepididae (eel cods) and Zoarcidae (eelpouts).

The more common families of demersal and benthic species are discussed below.

Rajidae and Arhynchobatidae

Four skate species are known to exist in the Ross Sea region including *Amblyraja georgiana*, *Bathyraja maccaini*, *B.* n. sp. cf. *eatonii*, and *B.* n. sp. (dwarf) (Smith *et al.* 2008, 2012), and all were caught during the two surveys. The record of *Bathyraja meridionalis* from the Ross Sea by Stehmann & Bürkel (1990) is not supported by voucher material despite extensive collecting by observers over the last decade and should probably be discounted. *Amblyraja georgiana* was only taken from the Balleny Islands at 520–1395 m depth during the surveys, but has been collected from the Ross Sea slope and from throughout the wider region in the fishery. All three species of *Bathyraja* were caught off Cape Adare in low numbers during both surveys in 230–1420 m depth and have also been taken on the shelf and slope in the fishery.

Muraenolepididae

Chiu & Markle (1990) listed four species in the genus *Muraenolepis* for the Southern Ocean. Subsequently descriptions of five new species, and a reallocation of an earlier species into a new genus, were published by Russian researchers (e.g. Balushkin & Prirodina 2010a, 2010b). Eight specimens were collected on the BioRoss survey and 13 on the IPY survey across a range of depths (456–1200 m) and areas. A total of 160 specimens have been returned by observers caught from within the Ross Sea and a further

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76 from the rest of the Ross Sea region. Re-examination of the IPY-CAML material resulted in identification of all of the specimens as *M. evseenkoi*. Following Balushkin & Prirodina (2010b), we have assumed that earlier records of *M. microps* from the Ross Sea were *M. evseenkoi*.

Macrouridae

Iwamoto (1990) recorded 11 species in four genera from the Southern Ocean. The most abundant and commonly caught species in the Ross Sea region was previously thought to be *Macrourus whitsoni* (Hanchet *et al.* 2003). However, as discussed earlier, after the IPY-CAML survey was completed genetic analysis showed that specimens originally identified as *M. whitsoni* comprised two species: *M. whitsoni* and a new sympatric species *M. caml* (McMillan *et al.* 2012). Both species were caught from the Ross Sea and northern seamounts in the survey in depths of 400–2000 m but the full extent of their distributions have yet to be established. Both *M. holotrachys* and *M. carinatus* have been taken in the fishery north of 65°S (McMillan *et al.* 2012).

The cosmopolitan *Coryphaenoides armatus* was collected at 66°39'S by observers, but was not taken on either BioRoss or IPY-CAML surveys. *Coryphaenoides ferrieri* and *C. lecointei* were taken during the IPY-CAML survey off the Scott Seamounts at over 3200 m depth, and a single specimen of the latter caught at *c.* 3500 m depth in the Brenke Sled. The more pelagic *Cynomacrurus piriei* was also taken from the Ross Sea and northern seamounts during both surveys.

Moridae

Morid cods are widespread in the deep ocean, but poorly represented from the Southern Ocean and had not been previously reported from the Ross Sea. *Antimora rostrata* was collected during both surveys from the northern seamounts in 700–1450 m depth. It has also been widely collected by observers from throughout the Ross Sea region including from the shelf and slope of the Ross Sea (off Franklin Island and from the Iselin Bank respectively). *Halargyreus johnsonii* was collected during both surveys from the Balleny Islands and north Scott Seamount in 850–1200 m depth. Observers have returned 17 specimens of *Lepidion* n. sp.cf. *schmidti*, 310–990 mm SL, taken in the fishery north of 64°06'S, which represents a new record for the Southern Ocean. A single specimen of *L.* sp.?*ensiferus* was also collected by observers on the Pacific-Antarctic Rise. The genus *Lepidion* is in need of a global revision.

Liparidae

At least thirteen species of liparid had previously been reported from the Ross Sea (e.g. Eastman & Hubold 1999). Only one liparid was caught during the BioRoss survey but an additional 26 specimens were captured during the IPY-CAML survey predominantly deeper than 1200 m, whilst other specimens have been directly taken on hooks or recovered from stomachs of toothfish caught by the fishery on the Ross Sea slope. Stein (2012) revised the Liparidae of the Ross Sea and wider Ross Sea region, describing 18 new species and three new records, making a total of 35 species in all. The two deepest demersal trawls yielded the greatest number of new species in this family.

Zoarcidae

Four zoarcids were reported from the Ross Sea by Eastman & Hubold (1999), with an additional species reported by Struthers & Møller (2009) and other species being described from north of the region (Møller & Stewart 2006). A total of 23 and 18 specimens were collected during the BioRoss and IPY-CAML surveys respectively. Three putative new species and one new genus were taken during the IPY-CAML survey and are currently under investigation by P. Møller (Zoological Museum, University of Copenhagen) and E. Anderson (South African Institute for Aquatic Biodiversity). In addition, range extensions were made for *Melanostigma vitiazi*, *Seleniolycus laevifasciatus*, and *Lycenchelys antarctica*. The highly speciose genus *Pachycara* is currently being revised by Møller, with a number of new species to be described.

Nototheniidae

A total of 18 species of notothenid had previously been reported for the Ross Sea (Eastman & Hubold 1999) with an additional six species from other published sources. The two surveys caught 16 species in the Ross Sea and an additional species from the northern seamounts. The distribution and relative abundance of the four most common species *L. squamifrons*, *P. antarctica*, *T. eulepidotus*, and *T. lepidorhinus* were outlined above. Most of the remaining specimens were in the genus *Trematomus*, and included most of the species reported from the region by earlier papers. *Trematomus bernacchii* was only caught around Cape Adare and the Balleny Islands at shallow to intermediate depths (70–740 m). *Trematomus hansoni* was only taken once on each survey and *T. tokarevi* was only caught off Cape Adare. *Trematomus newnesi* was sampled in shallow water around Cape Adare and the Balleny Islands (75–325 m) but only taken twice on the Mawson Bank on the IPY-CAML survey. *Trematomus pennellii* was only taken once on the IPY-CAML survey on the Mawson Bank, but was well represented on BioRoss around Cape Adare and the Balleny Islands at shallow to intermediate depths (63–675 m). *Trematomus scotti* was well represented in both surveys and was a frequent prey item in the stomachs of toothfishes.

Lepidonotothen larseni was only found at the Balleny Islands in depths of < 600 m. Seven *Aethotaxis mitopteryx* were caught during both BioRoss and IPY-CAML across a wide range of depths and areas. Small numbers of *D. mawsoni* (75–180 cm total length) were collected from the Ross Sea shelf, slope and seamounts during both surveys, and one *D. eleginoides* was collected from the Balleny Islands. *Dissostichus mawsoni* has been widely taken in the fishery, extending from the continent north to 60°S (Hanchet *et al.* 2010). Although *D. eleginoides* is most commonly caught north of 62°S, specimens have been caught on the slope of the Ross Sea at *c.* 72°S.

Artedidraconidae

The two surveys caught 11 of the 18 species of artedraconid listed for the Ross Sea by Eastman & Hubold (1999). *Artedidraco loennbergi*, *A. orianae*, *A. shackletoni* and *A. skottsbergi* were commonly taken at nearshore stations on BioRoss using the demersal trawl, beam trawl and the epibenthic sled at 85–506 m depth, often shallower than 300 m. *Dolloidraco longedorsalis* and *Histiodraco velifer* were only taken by IPY-CAML inside the Ross Sea, often concurrently, at depths of 447–926 and 447–530 m respectively.

The problems of identification of the most specious genus *Pogonophryne* have been well articulated (see Eakin *et al.* 2009). Distribution of the genus in the Ross Sea region appears to be restricted to the Ross Sea from inshore to 2000 m depth as no specimens were taken from the seamounts. The most abundant species taken on both surveys was *P. scotti* which was taken from throughout the Ross Sea at 191–752 m, most often deeper than 400 m. Three other species were infrequently taken in 365–752 m: *P. barsukovi*, *P. marmorata*, and *P. mentella*. Sampling the lower slope using the demersal trawl caught three specimens of the rare *P. immaculata* (see Eakin *et al.* 2009), and the paucity of sampling in this depth throughout the Southern Ocean is reflected by the low number of specimens in collections.

Bathydraconidae

The two surveys caught all ten species of bathdraconid which had previously been reported for the Ross Sea by Eastman & Hubold (1999). In addition, the IPY-CAML survey provided the first record for *Bathydraco antarcticus* from the lower slope of the Ross Sea (1620–1990 m) on the north-west Mawson Bank. *Bathydraco marri* was the most commonly caught representative, with 96 specimens, and comprised over 50% of the total number of bathydraconids (187) taken by the two surveys. *Bathydraco marri* was taken from throughout the western Ross Sea at intermediate depths (320–980 m). Within the Ross Sea, a number of specimens of species listed as rare in Eastman & Hubold (1999) were also collected. *Bathydraco scotiae* was collected in deep water (1954–2283 m) on the north-west edge of the Mawson Bank. *Prionodraco evansii* was commonly caught but restricted to 191–375 m in the western Ross Sea. Only one species of bathydraconid (*Gymnodraco acuticeps*) was taken outside of the Ross Sea with six specimens from the Balleny Islands at 125–295 m depth and one specimen from the Admiralty Seamount at 566–920 m.

Channichthyidae

The two surveys caught all eight species of channichthyids previously reported for the Ross Sea by Eastman & Hubold (1999) as well as *C. atkinsoni* and *C. dewitti*. The distribution and relative abundance of the commonest species *C. dewitti*, *N. ionah*, *C. myersi*, and *C. hamatus* were outlined previously. Most species were restricted to the shelf and slope of the Ross Sea but *Pagetopsis maculatus*, *N. ionah*, and *C. dewitti* were also recorded from the seamounts. *Cryodraco antarcticus*, *C. atkinsoni*, and *Pagetopsis macropterus* were all confined to shallow waters (50–675 m) of the shelf. The IPY-CAML survey caught both greater numbers of specimens and a wider range of species including *Dacodraco hunteri*, previously considered a rare species. Generally, channichthyids were caught at shallow to intermediate depths (50–864 m), the exception being *C. dewitti* which was taken in deeper water (to 1990 m) on the slope as well as on the Scott and Admiralty seamounts.

Faunal comparisons of species-richness and diversity

Based on presence/absence data from the two surveys considered here, Clark *et al.* (2010) identified three broad demersal fish assemblages in the southern Ross Sea (south of 74°S), central–northern Ross Sea (between latitudes 71° and 74°S), and the seamounts further north (65°–68°S). In the present study we found marked differences in patterns of diversity in demersal fish along the same latitudinal gradient. The highest species-richness and evenness indices were recorded from the shelf and the lowest recorded from the seamounts. The reduced evenness and diversity indices on the slope and north can be attributed to the local abundance of *L. squamifrons* and *Macrourus* spp., with several relatively large catches each exceeding 100 kg.The values for the various diversity indices calculated for the current study generally encompass the range for those calculated for the western Ross Sea by Eastman & Hubold (1999) and for the eastern Ross Sea by Donnelly *et al.* (2004). The mean values for the Shannon-Weaver index of 1.88 and 1.79 reported by Eastman & Hubold (1999) for the Ross and Weddell Seas respectively were substantially higher than our comparable value of 1.47 for the Ross Sea shelf. In contrast, the Margalef values in the current study (0.83–4.20) were generally higher than those reported by Causse *et al.* (2011) (0.00–2.16) for the Dumont d'Urville Sea covering a similar depth range to the current study.

A total of 53 demersal species was found during the two surveys from the Ross Sea shelf, a slight increase on the 47 species found by Eastman & Hubold (1999). An additional nine species were recorded from the Ross Sea slope, and the extrapolated species-richness for the Ross Sea (shelf and slope) as a whole was 77 species. However, when the data from sources were combined, including the large number of previously undescribed species of liparid, the total number of species equalled 117. This is considerably larger than the Weddell Sea demersal fish fauna which includes 83 species in 14 families (in Eastman & Hubold (1999)). The large increase in the number of fish recorded in the Ross Sea reflects the greater depths and wider range of sampling gear used in the current study as well as the discovery of cryptic species in several families in the intervening period including Liparidae, Zoarcidae, Muraenolepidae etc.

The pelagic species showed quite different patterns of diversity to the demersal species. The highest richness and evenness indices were recorded from the seamounts and abyssal stations and the lowest recorded from the shelf. The reduced evenness and diversity indices on the shelf can be attributed to the local abundance of *P. antarctica*, which were caught in large numbers at almost all the shelf stations. The marked change in species assemblage from a myctophid dominated assemblage over the continental slope and the open ocean to a *P. antarctica* dominated assemblage on the shelf has been recorded in all previous studies around Antarctica (De Witt 1970, Hubold & Ekau 1987, Donnelly *et al.* 2004). However, the number of pelagic species in each assemblage has varied considerably between studies. The 24 pelagic species reported in the present study was the same as that reported by Hubold & Ekau (1987) from the Weddell Sea, but much higher than the nine species reported by Donnelly *et al.* (2004) in the eastern Ross Sea. The extrapolated asymptotic richness estimated to be 35 species suggests other species would be found with additional sampling. Apart from counts of species-richness we could find no published studies which have investigated other measures of pelagic fish diversity around Antarctica.

Based on the material collected in this study, combined with previous published material, the total fish species count for the Ross Sea region is now 175 of which 135 species were recorded from the Ross Sea shelf and slope.

Catch rates and biomass

Mean catch rates of all species for the Ross Sea shelf and slope strata were $< 1000\,\text{kg}\,\text{km}^{-2}$ indicating relatively low densities throughout the area. However, these low catch rates are consistent with catch rates from previous studies around the Antarctic continent. Eastman & Hubold (1999) reported catch rates of 90 and $438\,\text{kg}\,\text{km}^{-2}$ for two stations on the Ross shelf, whilst Donnelly *et al.* (2004) reported catch rates of $700–3500\,\text{kg}\,\text{km}^{-2}$ from the eastern Ross Sea, and Ekau (1990) reported catch rates of $100–3400\,\text{kg}\,\text{km}^{-2}$ for the Weddell Sea. Catch rates in the current study were highest in 200–400 m, whereas in the eastern Ross Sea and Weddell Sea they were highest on the shelf edge in 450–700 m.

A major objective of the IPY-CAML survey was to estimate the biomass of demersal fish species taken as bycatch of the toothfish fishery. Although the survey area was severely restricted due to the ice conditions, we were able to obtain biomass estimates of demersal fish for parts of the shelf and slope for the first time. We note that these biomass estimates and coefficients of variation should be treated with caution because they assume that all fish in the path of the wings of the trawl are caught and make no allowance for the herding effect of the otter boards or for the escapement of fish through the meshes of the net, under the ground gear or above the head line. The latter is particular relevant to the Ross Sea where many species have a bentho-pelagic or pelagic lifestyle (Vacchi *et al.* 2000).

Conversely, despite it generally being considered as a pelagic species, *P. antarctica* was the most abundant species (by number and by weight) in the demersal trawl catches on the shelf and formed 40% of the biomass in the shelf strata. The biomass estimate from the trawl survey was about 10% of that from the acoustic survey of the area by O'Driscoll *et al.* (2011). Indeed, there is growing evidence that *P. antarctica* should be classed as a bentho-pelagic species (Causse *et al.* 2011). O'Driscoll *et al.* (2011) noted that *P. antarctica* often occurred in acoustic layers close to the bottom, whilst Causse *et al.* (2011) noted that it was present close to the bottom in photographs and videos. During the present expedition it was also recorded on 15 separate occasions on videos within 2–3 m of the seabed.

The three icefish species *C. hamatus*, *C. myersi*, and *N. ionah* together contributed to about 15% of the biomass in the shelf strata. All three species were caught in the midwater trawl, and in the case of *N. ionah* sometimes in the upper surface water, and so the survey undoubtedly also underestimated the abundance of these species. The two most commonly occurring nototheniids made up 6% of the biomass.

The estimates of biomass in the slope strata may be more reliable. The biomass was dominated by *Macrourus* spp., which contributed to 65% of the total biomass on the slope. *Macrourus* spp. are also the main bycatch in the toothfish fishery on the slope contributing to 5–10% of the total fish catch, whilst species such as *C. dewitti*, *A. rostrata*, and *Muraenolepis* spp. contribute to < 1% (Hanchet *et al.* 2003). The preliminary estimates of *Macrourus* spp. biomass from the survey have also been used to provide advice on setting precautionary catch limits for *Macrourus* spp. in the fishery (SC-CAMLR 2011).

Collections from the two surveys and the additional samples collected from the toothfish fishery have contributed to a substantial increase in the number of species recorded for the Ross Sea and wider Ross Sea region. However, the distribution of smaller fishes in areas of the slope in the eastern Ross Sea is still poorly known. The lower slope region in the Ross Sea was of greatest interest in terms of new taxonomic discoveries but the encroaching ice and lowering temperatures meant that the planned sampling had to be cut short. The collections that were made contained the greatest number of new records and new species, indicating that the lower slope contains many more species of fishes and invertebrates yet to be discovered. The costs and logistics of working in the Ross Sea mean that a collaborative international survey would be the best chance of finishing this work.

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Supplemental material

Two supplemental tables will be found at http://dx.doi.org/10.1017/S0954102012001265.

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